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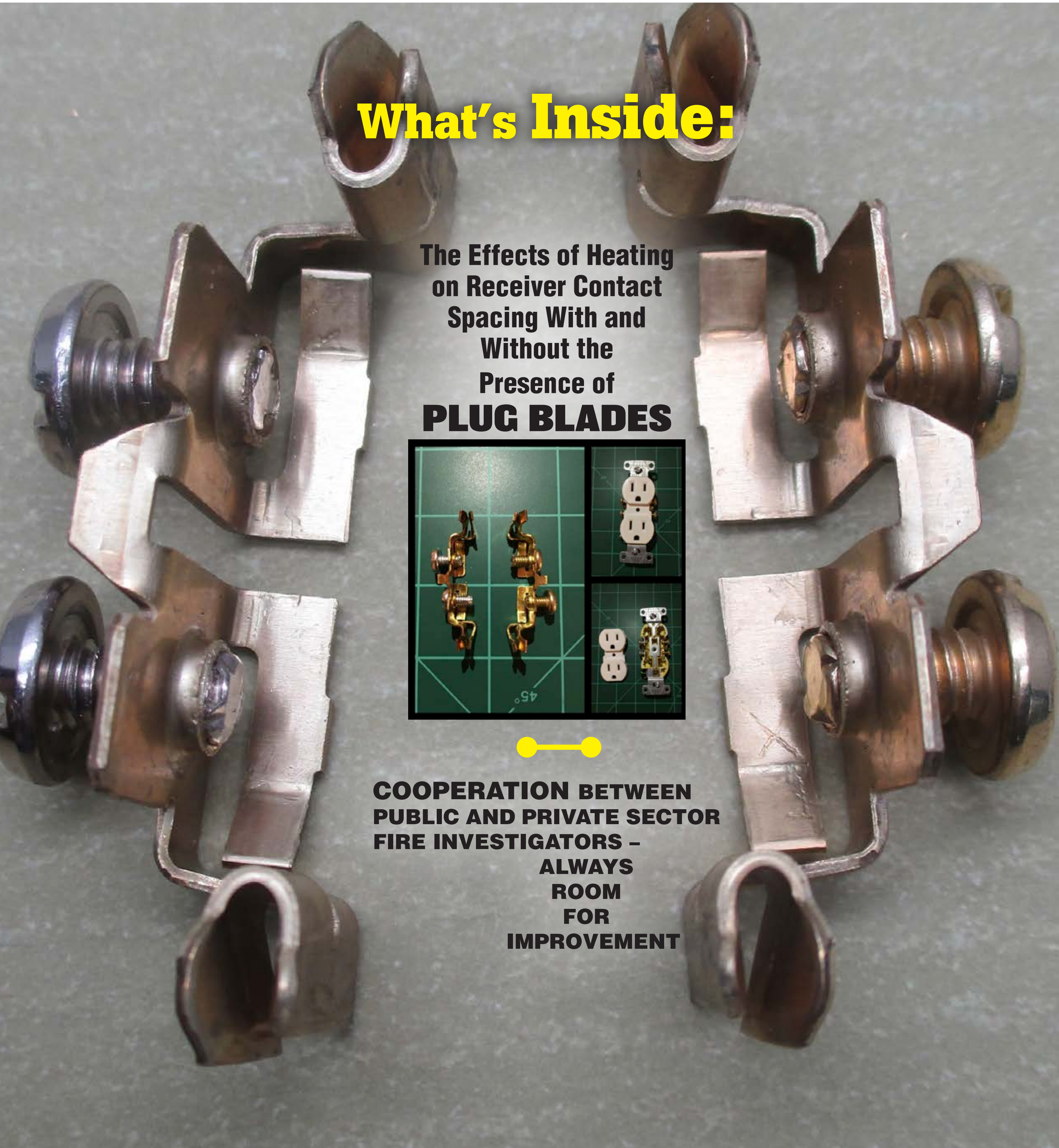

What's Inside:

The Effects of Heating on Receiver Contact Spacing With and Without the Presence of PLUG BLADES

COOPERATION BETWEEN PUBLIC AND PRIVATE SECTOR FIRE INVESTIGATORS – ALWAYS ROOM FOR IMPROVEMENT

OP-ed

IAAI welcomes member input - for technical review or non-technical consideration

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Prof. Niamh Nic Daeid, Ph.D

Arc Mapping Research - a clarification

The purpose of this paper is to revisit foundational arc mapping research published by Nick Carey and Nic Daeid in this journal in 2010 [1], and to respond to two reviews authored by Babrauskas published in 2017 and 2018 [2, 3], where the data generated in Carey's research was used erroneously to present incorrect conclusions in regards to the scientific nature and efficacy of arc mapping methodology [4-7].

Recent review papers by Babrauskas have erroneously and incorrectly analysed the results of our experimental fires by using the data generated from these experiments out of context. As a result incorrect conclusions have been drawn and these have been used to unjustifiably criticise the overall arc mapping methodology without, in our view, any scientific justification for doing so. Additionally, in 2018, Dr. Babrauskas agreed that he had not undertaken any of his own arc mapping experiments, or used arc mapping methodology during fire scene examinations that he had undertaken professionally [10].

Who should undertake Arc Mapping or other electrical surveys?

A thorough understanding of the routing of an electrical installation within typical buildings is essential before attempting to undertake arc mapping or other similar detailed electrical surveys. Such knowledge would include, but may not be limited to, sufficient in-depth theoretical knowledge and practical training of the wiring practices and regulations within the appropriate jurisdiction. In the UK, this would involve a working knowledge of British Standard (BS) 7671, (also known as the IET [8] electrical wiring regulations), whereas in North America a working knowledge of NFPA 70 [9] or the applicable building electrical code would be necessary.

Without a thorough knowledge and understanding of common wiring practices, there is an increased risk of misinterpreting electric arcing evidence which may be found at a fire scene, particularly in cases where electrical cables may not be exposed to the early development of the fire.

In addition, localised melting from other effects (mechanical, thermal and occasionally alloying) can be erroneously determined as electric arcing evidence. As a result, a thorough understanding of localised melting damage and the correct identification of the key indicators of such damage is essential to prevent misinterpretation of the electrical evidence.

Routing and containment of electrical cables.

In the UK it is permissible to fix cables directly on to the surface of a wall, ceiling or exposed timber beams etc. This type of installation would include 'Twin & Earth' cable (also known generically as 'Romex' or non-metallic cable in the North America), where insulated live and neutral conductors and a bare earth/ground conductors are enclosed within a PVC sheath[1]. Figure 1 illustrates this type of installation method within an older style of building in the UK, where cables were clipped onto exposed timber beams and the surface of walls. Also in the UK and within Europe, electrical cables are also often contained within PVC plastic conduit and/or trunking on the surface of walls and ceilings in residential and commercial buildings. In these circumstances the cables are generally exposed to the effects of early fire development as the PVC containment is rapidly destroyed. If the cables are not surface mounted, a time lag/delay needs to be taken into consideration, before the electrical cables interact with the fire. This is because cables, in the UK and other countries, are also often routed within plaster, or behind plasterboard (drywall) linings. There may also be situations, i.e. smaller fires, where the fire never interacts with the fixed wiring within a building.

Insulated conductors contained within metal conduit or trunking fixed to wall / ceiling surfaces allow heat to rapidly conduct into the metal conduit and trunking and live to earth faults often occur close to where the fire originated. The majority of commercial/industrial electrical installations using metal containment systems provide a sufficient network which connects sockets, light fittings and other fixed equipment and consideration needs to be given to the routing of the metal conduit/trunking in evaluating the physical evidence recovered during the fire scene investigation.

Figure 1:
A UK house with exposed timber floor and ceiling beams where Twin & Earth cables have been clipped to the beam.

Carey and Nic Daeid [1] generated the first ground truth data set for arc mapping – that is a data set where all of the experimental conditions were known – which incorporated repetitive testing of the three-dimensional location data for the arcing damage on an electrical cable and the fire's area of origin collected during a series of full-scale experimental fires. The experiments undertaken involved the surface mounting of 4 electrical circuits into compartments where fires were started in specific ways and in known areas of origin. Multiple tests were undertaken using the same experimental set up providing scientific rigour to the data and enabling statistical analysis to be undertaken.

A mathematical method was established and validated to explore the relationship between the fire's area of origin and the arcing damage locations [7]. Figure 2 illustrates the use of x,y,z co-ordinates to provide a three dimensional location within the compartment/room for both the area of origin of the fire and the observed arc damage onto surface mounted electrical cables.

x_o, y_o and z_o co-ordinates were used to describe the centre of fire's area of origin where the defined area of origin was the size at the base of the fire when the plume reached the ceiling. The xj,yj,zj co-ordinates documented the arcing damage locations on each separate electrical circuit within the compartment.

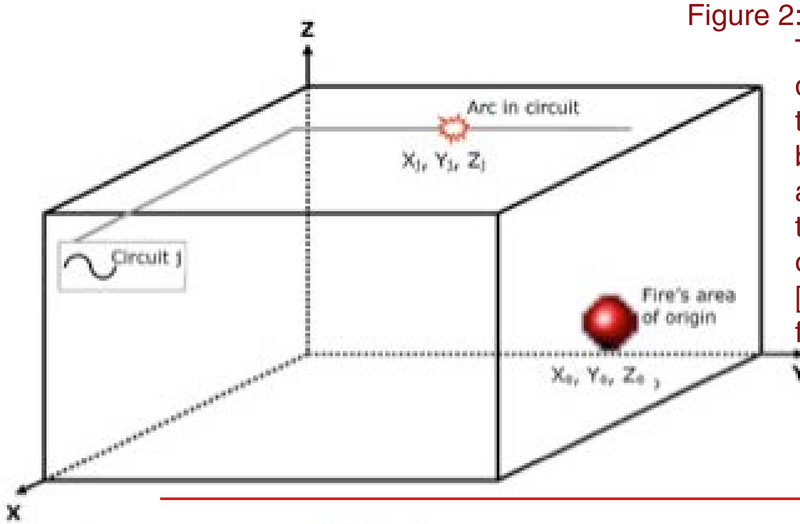

Figure 2:
Three-dimensional diagram showing the relationship between the fire's area of origin and the arcing damage on one circuit [reproduced from ref1]

Figure 3 presents a cross-sectional view of a compartment, the fire's area of origin, the location of arcing on an electrical circuit and the minimum distance between the electrical circuit and the fire's area of origin. Roj is the distance between the fire's area of origin and the arcing point on a circuit in the experimental fires and Rmin is the minimum possible distance between the centre of the fire's area of origin and the circuit that sustained the arcing damage.

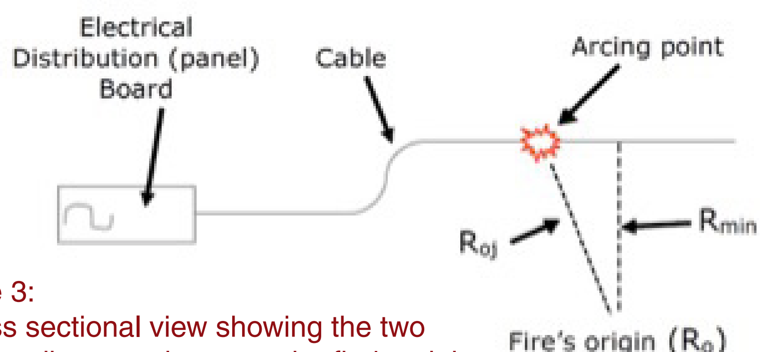

Figure 3:
A cross sectional view showing the two different distances between the fire's origin and both the arcing point on a surface mounted cable and the minimum distance between the fire and the cable [reproduced from ref 1]

[1]In North America the conductors may also be covered in additional material i.e. paper. In Europe stranded live, neutral and earth conductors are all individually insulated and surrounded by a PVC sheath.

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Arc Mapping Research - a clarification

The data for Roj and Rmin for each of the four energised circuits in each compartment were inputted into mathematical software using the x,y,z co-ordinates for all locations of the area of origin for each of the experimental fires, the arcing locations on the circuit, and the closest possible arcing location on the circuit from the fire origin. The formulas to calculate Rmin / Roj were also inputted and the data was analysed and the three-dimensional location of the arcing damage for each circuit was compared to the closest point on that circuit to the fire's area of origin in each case and the results are detailed in Figure 4.

Statistical analysis suggested that under the experimental conditions used, there was a high probability (85% or higher at the 95% confidence level)

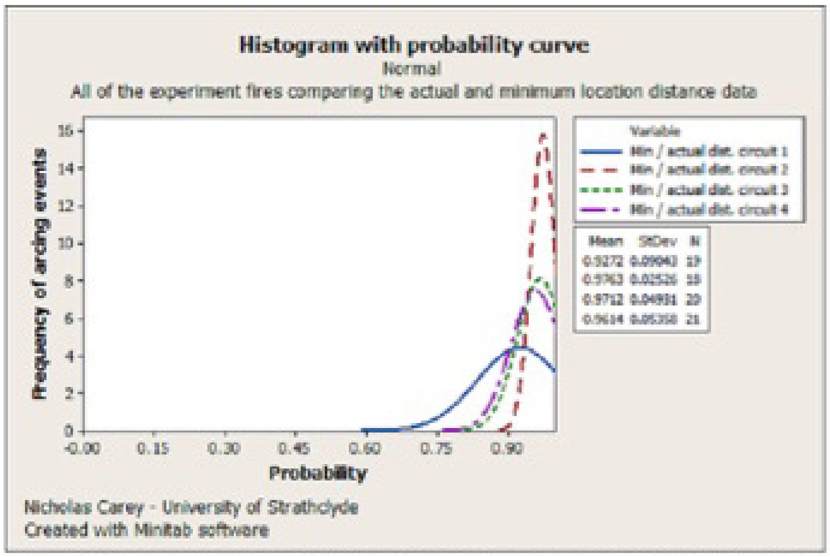

Figure 4:
A histogram detailing the probability of the arcing damage compared to the closest point on a circuit (note the histogram "Probability" range axis) [updated version of the histogram presented in ref 1]

that the arcing occurred on a circuit within a close proximity to the fires area of origin, where the cables were surface mounted on the wall and ceiling linings.

A reduced probability for circuit 1 was observed for almost all of the experiments. The location of the cable for circuit 1 (the power ring[2] circuit configuration) in each experiment was consistent throughout all of the experimental fires. The cable was located at the junction of the top of the walls and the ceiling. The fire dynamics appear to have slightly delayed the exposure of the PVC insulation to the heat flux in the fire's early development resulting in arcing damage occurring further away from the area of origin in some cases and a greater spread of results as a consequence.

Recent arc mapping review papers

Two review papers authored by Babrauskas [2,3] reviewed arc mapping methodology and the experiments undertaken by Carey [7] and others, however Babrauskas explained that in these reviews he had not undertaken any of his own experiments, or attempted to use the arc mapping methodology during fire scene examinations himself [10].

The more recent of Babrauskas' review papers [3] included a table of results generated by Babrauskas from the original data presented within Carey's PhD thesis [7]; however a number of errors were introduced by Babrauskas into the dataset presented. In the first instance, the data contained within the PhD thesis was generated in regard to a specific research question and would not be scientifically valid for the purpose that it was being used by Babrauskas [3] in his exploration of "Arc beads near ventilation sources" . As such, any interpretation of the data that has been made in relation to correlations between arc beads and ventilation openings is highly questionable and provides erroneous interpretations of ventilation effects during the development of the fires. This is particularly important as the majority of the window openings in the experimental fires did not fail until after the electric arcing had occurred, with subsequent operation of circuit protection devices. As such, linkage of the arcing damage to ventilation effects using the data from Carey's PhD thesis [7] is scientifically untenable. Other errors included a suggestion that arcing was found close to ventilation sources in 51.1% of arcing locations whereas the original researchers reported this to occur in 2.44% of arcing locations.

Babrauskas also used Carey's PhD data to explore "Arc beads near heavy fuel" and while a number of the experimental fires used to generate Carey's data contained large fuel packages (i.e. upholstered furniture etc.) Babrauskas' suggestion that arcing occurred close to large fuel packages on 61.4% of occasions is incorrect. In fact, the researchers determined that such physical evidence was apparent in 84.71% of occasions. The large fuel packages in the experiment fires were consistent with conventional furniture layouts within residential/commercial compartments of similar sizes to the experimental ones. The close association with arcing locations and large fuel packages is not surprising, and investigators undertaking arc mapping should consider large fuel packages along with any other relevant information when undertaking a post-fire electrical survey.

[2]Ring circuits are often used in the UK and Ireland or other countries which have historically adopted the UK wiring installation configuration. The cables forming the ring circuit originate and return to the same circuit protection device, neutral and earth connections within a consumer unit/distribution/panel board and are routed to an unlimited number of sockets/receptacles in a 100m2 area. BS7671 limits the Impedance values of ring and other circuits dependent upon the type of circuit protection device used.

Figures 5 and 6 illustrate sections of two diagrams detailing two experimental fires which were part of the Carey data set (#21 and #29). Babrauskas has, in our view, erroneously reported that none of the arcing observed on the circuits within these fire scenes had occurred close to the fire's origin as annotated on the diagrams and this is not in fact, the case. The diagrams for experiments 21 and 29 clearly show that arcing occurred on different circuits within 1 metre (approximately 3 feet) of the fire's defined area of origin.

Overall Babrauskas reported arcing as being close to the fire's origin in 22.7% of the available occasions, whereas the researchers who actually undertook the experimental fires and the subsequent analysis, reported arcing within 1 meter of the fire's area of origin in over 85% of occasions.

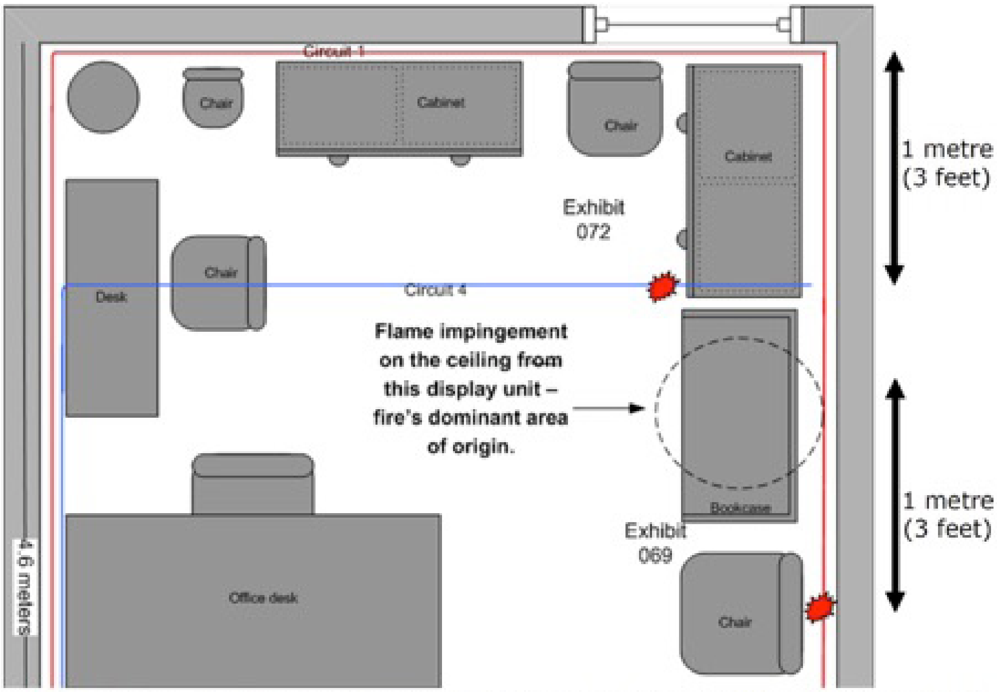

Figure 5:
Showing the area above a timber bookcase within a section of the compartment in experimental fire number 21. The red coloured points denote the arcing damage on the fire damaged conductors.

Babrauskas has stated that the arc mapping methodology does not follow the principles of fire scene or electrical science and describes it as being "tedious" and "laborious" [2,3]. Arcing as an event has a strong and robust scientific underpinning dating back some 200 years and has been identified for decades as generating physical evidence identified both by electricians and electrical engineers at sites of electrical failures (i.e. failures within switchgear panels), and by fire investigators at fire scenes. The evaluation of arcing evidence follows established scientific and engineering principles and should be undertaken by individuals with a strong electrical installation background, with the appropriate training and experience, along with a thorough understanding of indicators of arcing, to reduce the risk of an incorrect interpretation of arcing damage. Fire investigation requires both time and a detailed meticulous approach, where fire investigators need to be methodical and thorough; requiring time, commitment and attention to detail. Therefore, viewing any aspect of this work as being tedious or laborious is incompatible with professional practice. Electrical surveys, including the use of the arc mapping methodology, where appropriate, should form a part of a fire scene examination, especially when the information from fire patterns is unclear (i.e. post-flashover scenes) and appropriate care, time and attention is fundamental to any fire investigation.

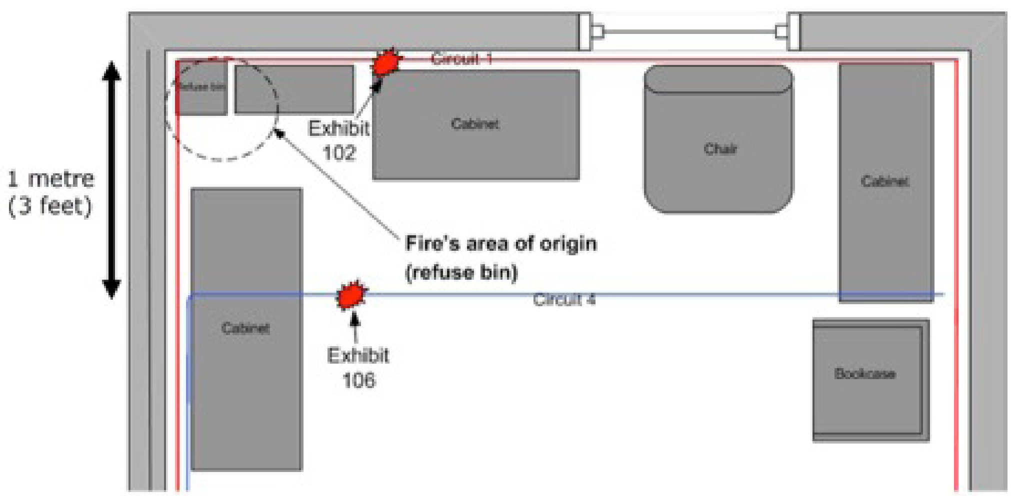

Figure 6:
Showing an area close to a refuse bin where the fire was started in experimental fire number 29.

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Conclusions

Analysis of the three-dimensional data recorded during the 2003 to 2009 experiments and other more recent experimental fires, along with the location of the associated arcing artefacts, indicated that there was a high probability of electric arcing damage occurring to electrical conductors within surface mounted cables which were located close to the origin of a fire. The series of full-scale experimental fires with repeated scenarios scientifically validated the reliability of the arc mapping methodology and confirmed that the arcing events occurred irrespective to the fuel loads and fuel configuration within the compartment.

Recent review papers by Babrauskas have erroneously and incorrectly analysed the results of our experimental fires by using the data out of context and as a result they have drawn incorrect conclusions to criticise the overall arc mapping methodology without scientific justification for doing so.

References

1. Arc mapping *Fire & Arson Investigator*, October 2010
2. Babrauskas, V. (2017). Arc Mapping: New Science or New Myth? *Fire and Materials*, San Francisco, CA.
3. Babrauskas, V. Arc Mapping: A Critical Review, *Fire Technology* (2018) 54: 749.
4. Svare, M.J., M. Dubbin, and N.J. Carey. *Reconstructing the fire scene using the electrical system. International Association of Arson Investigators, ATC*. 2006. Denver, USA.
5. Carey, N.J. and Nic Daeid, N., *The metallic damage to electrical conductors at fire scenes*, in *Interflam* 2007. Interscience Communications: University of London, Royal Holloway College, Egham, Surrey.
6. Quintiere J., *Calculations to undertake a probability analysis of three-dimensional points*. Personal communication - 2007.
7. Carey, N. J. PhD thesis, *Developing a reliable systematic analysis for arc fault mapping.* Centre for Forensic Science - Pure & Applied Chemistry. 2009, University of Strathclyde, Glasgow.
8. IET: Institute of Engineering and Technology (formally known as the Institute of Electrical Engineers (IEE)).
9. National Fire Protection (NFPA) 70, the National Electrical Code (NEC®).
10. The Four Corners of Origin Determination: Witness Statements, Fire Patterns, Arc Mapping and Fire Dynamics. *International Association of Arson Investigators International Training Conference*, Frisco, Texas, USA, 2018.